Japan (East) Sea Dynamics Using Numerical Models
With 1/8° to 1/64° Resolution

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LONG-TERM GOALS

Investigate Japan/East Sea circulation dynamics with a suite of numerical ocean circulation models, and verify numerical results via model-data comparisons.

OBJECTIVES

Investigate Japan/East Sea circulation dynamics in a systematic and progressive fashion using a sequence of increasingly complex ocean models and model-data comparisons. Investigate the impact of upper ocean - topographical coupling and isopycnal outcropping on the mean pathways of the major current systems, including those over the continental shelf region. Also, to assess the impact of different wind forcing on the JES circulation, with emphasis on the branching of the Tsushima Warm Current (TWC).

APPROACH

This is a modeling study that utilizes a sequence of progressively sophisticated ocean models to investigate circulation dynamics in the JES. In each case a range of resolutions is used, 1/8° to 1/64°, to assess the impact of resolution on model realism and model dynamics. During the first year the NRL Layered Ocean Model (NLOM), which is mainly isopycnal in design, was used to investigate the roles of upper ocean – topographical coupling and isopycnal outcropping. These simulations included features like nonlinearity, bottom topography, multiple vertical modes, flow instabilities, isopycnal outcropping, diapycnal mixing, overturning cells in the vertical, thermodynamics, and thermal forcing. This first phase was followed (and is continuing) with simulations performed with the Miami Isopycnal Coordinate Ocean Model (MICOM), which allows the interfaces to intersect the bottom topography, the existence of zero-thickness layers, and includes the shelf circulation with limited vertical resolution. Concurrent with these studies are those that utilize the HYbrid Coordinate Ocean Model (HYCOM), a generalized vertical coordinate ocean model under joint development with the University of Miami and

the Los Alamos National Laboratory. This model has the advantage of total generality of the vertical coordinate system, i.e. it is isopycnal in the open, stratified ocean, but reverts to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates near the surface in the mixed layer. This generalized vertical coordinate approach is dynamic in space and time, and extends the range of applicability of traditional isopycnal coordinate ocean models such as NLOM and MICOM to shallow shelf regions and unstratified parts of the ocean. It also provides more vertical resolution near the surface everywhere. HYCOM was developed from MICOM using the theoretical foundation for implementing such a coordinate system which was set forth in Bleck and Boudra (1981) and Bleck and Benjamin (1993).

WORK COMPLETED

MICOM and HYCOM have been set up for the JES region, and several simulations have been completed at 1/8° with 10 or 15 coordinate surfaces in the vertical.

The implementation of the generalized vertical coordinate in HYCOM is complete, and simulations that use all three coordinate systems simultaneously have been performed. In HYCOM, the choice of the hybrid vertical coordinate is determined via the layered continuity equation, meaning that it is dynamic in space and time. This is of primary importance because the boundary current being investigated (the Nearshore Branch of the Tsushima Warm Current along the northern coast of Japan) is (partly) located over a shallow shelf region. A scalable version of HYCOM that uses open MP (suitable for shared memory machines) has been developed by Alan Wallcraft of NRL and a limited number of HYCOM simulations have also been performed at 1/16° and 1/32° resolution with that source code. Lateral boundary conditions have been implemented, in the form of relaxation to temperature, salinity, and interface depth at the inflow and outflow straits (the baroclinic component) together with a depth averaged flow based on a prescribed velocity (the barotropic component). Several simulations have been performed to determine the optimal number, combination, and structure of z-levels, sigma coordinates, and isopycnal coordinate surfaces. Options for either a Kraus-Turner (K/T) or K-Profile Parameterization (KPP) mixed layers have been implemented. Both have been tested, although most simulations to date have used the K/T mixed layer. Some simulations to determine the sensitivity of the model results to the external forcing, initial state, and model parameter space have also been completed, although to some extent these may depend on the final configuration of the vertical coordinate. Finally, several utilities have been written that allow for conversion from HYCOM style archive format to NLOM style history files. This allows diagnostic HYCOM results to be produced with existing NLOM diagnostic software that has been developed over the last several years.

RESULTS

Results from work done during the first two years of this DRI using NLOM are described in a journal article (Hogan and Hurlburt, in press for Oct. 2000 JPO) that demonstrates how high horizontal grid resolution, baroclinic instability, bottom topography, and isopycnal outcropping are crucial for realistically simulating the mean circulation and eddy field in the JES, particularly the separation of the East Korea Warm Current.

When forced with monthly climatological wind and heat flux forcing, the 1/8° HYCOM simulations realistically reproduce the basic current patterns in the JES. However, similar to the NLOM simulations

at the same (relatively coarse) resolution, the MICOM and HYCOM simulations also show overshoot of the observed separation latitude for the East Korea Warm Current along the Korean coast when forced with COADS monthly climatological winds and fluxes. Indeed, comparison of NLOM, MICOM, and HYCOM results, such as the seasonal mixed layer currents, are to first order, fairly similar. However, because of the inclusion of the shelf region and the high vertical resolution over the shelf, the HYCOM (and to a lesser extend, MICOM) results give a more realistic depiction of the Nearshore Branch of the Tsushima Warm Current. Additionally, as was noted in the journal article on the NLOM results mentioned above, as the resolution is increased to 1/16° in MICOM and HYCOM, there is increased eddy activity and the overshoot of the East Korea Warm Current is diminished, but not eliminated. It is anticipated that the 1/32° HYCOM simulation, when fully equilibrated will also depict realistic separation of this boundary current.

The use of the layered continuity equation to dynamically determine the vertical coordinate system in space and time is an important attribute of HYCOM. However, the *parameters* of the vertical structure must be carefully chosen. For instance, sufficient vertical resolution needs to be maintained near the surface, but isopycnal surfaces also should be able to exist near the surface locally. Additionally, sigma layers should exist only over the shallow shelf regions to avoid pressure gradient errors associated with steeply sloping bottom topography. These considerations have been taken into account in determining the optimal vertical configuration for investigating the Nearshore Branch over the shelf and along the shelf break. The vertical temperature structure from a 1/8° HYCOM simulation along 133.4°E is shown in Figure 1. During both winter and summer, vertical resolution via z-levels is always maintained near the surface, but more of the z-levels turn into isopycnal surfaces during the summer (Figure 1b) because of the less dense water near the surface.   This effect is also seen during the winter (Figure 1a), as z-levels progressively turn into isopycnal surfaces from north to south. Also during the winter, the depth of the mixed layer, depicted by the thick black line (Figure 1), is about 150m. Of particular interest is the nature of the vertical structure in the region of the Nearshore Branch. This current is largely barotropic over the shelf during the winter (Figure 1a), but clearly baroclinic during the summer (Figure 1b) as depicted by the tilted isopycnals near 36°N. This suggests that topographic control may be the dominant process associated with this boundary current during the winter, but that isopycnal outcropping may be more important during the summer. In both seasons, however, the bulk of the transport is seaward of the shelf break. However, these processes need to be investigated with higher horizontal resolution so that the area of the shelf is better resolved and amount of eddy viscosity can be reduced.

]IMPACT/APPLICATIONS

In the NLOM simulations described in the journal article, as the horizontal resolution is increased the widespread ability of topographic features to steer upper ocean currents becomes apparent, particularly with respect to the separation latitude of the East Korea Warm Current. This upper ocean topographic coupling occurs via baroclinic instability and requires that mesoscale eddies be very well resolved in order to maintain sufficient coupling. One goal of the current research is to determine if the same mechanism (and effect) is prevalent in HYCOM, which, like the 1/8° NLOM results, shows unrealistic overshoot of the East Korea Warm Current.

The HYCOM results shed light on the dynamics governing the Nearshore Branch, a boundary current along the north coast of Honshu (Japan). In particular, the barotropic structure of the current during

the winter suggests that topographic control may be the dominant process during this time, and the baroclinic structure during the summer suggests that isopycnal outcropping as the dominant mechanism, a finding supported by earlier NLOM simulations. However, higher resolution is needed for more definitive results in this region.

TRANSITIONS

NRL has funded 6.2 (ONR) and 6.4 (SPAWAR) projects to develop a 1/16° global nowcast/forecast system using NLOM coupled to a 1/8° Asian marginal seas model using the Navy Coastal Ocean Model (NCOM). However, the results presented in the submitted journal article suggest that neither of these will have adequate horizontal resolution in the JES. Therefore, a 1/32° JES model based on HYCOM could be transitioned as the JES component of this system.

RELATED PROJECTS

Matching funds were provided by 6.1 LINKS in FY00. Interaction with multinational CREAMS II project. Funded participant in the 6.1 HYCOM/NOPP project.

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PUBLICATIONS

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1/8° 15-layer JES HYCOM

Temperature cross-section along 133.4°E
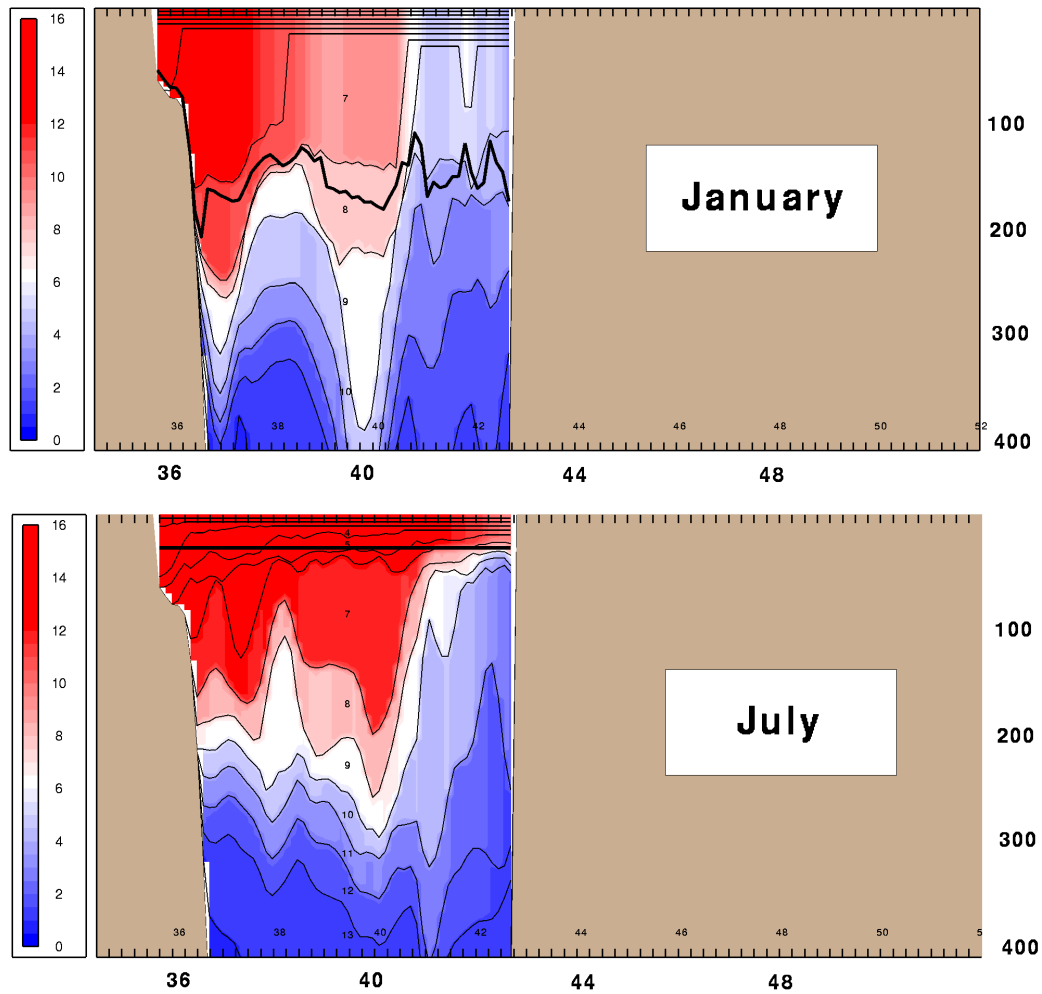
Figure 1. Simulated cross-sections of temperature along 133E from a 1/8 15-layer HYCOM simulation in the JES. The thick black line is the depth of the Kraus-Turner mixed layer.